Advances in Marine Deblending

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Summary

Simultaneous-source one-sided wide-azimuth (WAZ) acquisition has become an effective strategy for improving illumination in geologically complex frontier areas, but its alternating NAZ/WAZ shot pattern introduces challenges for conventional FK-domain deblending workflows. Existing methods such as ISTA assume uniformly sampled 3D shot volumes, an assumption violated by the interleaving and occasional irregularity of shots from dual-vessel acquisition. This paper introduces a new deblending approach that separates NAZ and WAZ shot gathers into two coherent sub-volumes, enabling effective FK-domain sparsity and high-fidelity reconstruction despite increased shot spacing. Results from an Angola 3D survey demonstrate that this strategy preserves data quality and is well suited for modern multi-vessel acquisition geometries.

Introduction

Simultaneous source one-sided wide-azimuth (WAZ) acquisition using enhanced-frequency sources has been developed and successfully applied in frontier regions to address the challenge of obtaining high-quality seismic data with adequate illumination of complex geological structures, while maintaining operational efficiency and economic viability (Ou *et al*. 2023; Donaldson *et al*. 2024; Widmaier *et al*. 2025).

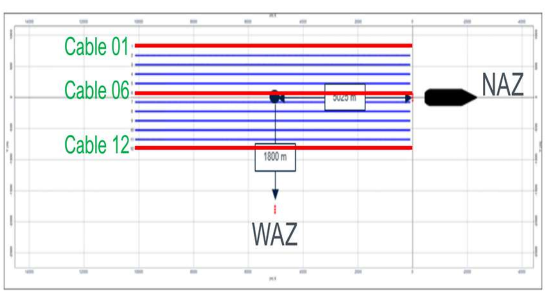

Figure 1: A schematic plot of one-sided WAZ streamer acquisition. One vessel towed twelve 10 km long streamers 150 m apart; the other one was dedicated to shooting abeam the spread streamers 1800 m from the center, where the red dots represent the sources.

Accurately imaging complex boundaries and deep geological structures requires the use of high-fidelity, amplitude-preserving processing algorithms. For simultaneous-source acquisitions, deblending is an essential component of the imaging workflow. This paper presents a new deblending strategy tailored for one-sided WAZ data and demonstrates that it delivers robust, high-quality results.

The one-sided WAZ acquisition geometry employs two vessels: a streamer vessel that tows both the source and the receiver cables, and a dedicated source vessel that sails abeam either the streamer vessel or the receiver spread. The streamer vessel records narrow-azimuth (NAZ) data, while the dedicated source vessel contributes the additional shots required for the WAZ data. The two source arrays fire alternately in a dithered sequence, enabling the simultaneous acquisition of both NAZ and WAZ data.

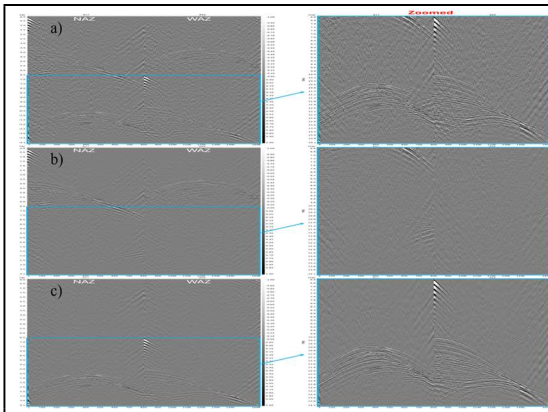

Figure 2: NAZ and WAZ shot-gather deblending. (a) input, (b) deblended model, and (c) difference. One the right are closeups of the cyan rectangles on the left. (Data Courtesy of TGS)

The coexistence of both NAZ and WAZ shot gathers presents a challenge to existing methodology of deblending. The Iterative Shrinkage-Thresholding Algorithm (ISTA) method (Sun *et al*. 2022) performs thresholding in 3D FK domain, and therefore assumes the 3D shot gathers are either all NAZ or all WAZ. Alternative NAZ and WAZ shot gathers plus any missing shots generate an irregular 3D volume that breaks the pre-requisite assumption.

To mitigate this, we sort our 3D shot gather volume into two sub-volumes, one NAZ sub-volume and one WAZ sub-volume. Though this may double the spacing between shots and generate aliasing, our examples from an Angola 3D dataset show that performing thresholding in the transformed FK domain of NAZ/WAZ sub-volumes gives high-accuracy results.

This proposed new method honors the data acquired through novel and efficient acquisition scenarios and safeguards the data fidelity for further processing. This method can be applied to any streamer acquisition with multiple source vessels. It may also be used in OBN or land deblending if data is sorted in the cross-spread domain as we do in streamer acquisition. The aliasing in OBN or land acquisition comes from large spacing between receivers than from alternative shots as in streamer acquisition. However, they both appear as “signal” in the FK domain for thresholding mechanism as we will see in the example and therefore won’t have negative effect on deblending.

Method

FK-domain-based ISTA methods have been extensively used in streamer data deblending and achieved considerable success (Sun *et al*. 2022, Kumar *et al*. 2023, Hu *et al*. 2024). The method works on a 3D volume made of consecutive shot gathers; events in the shot domain unlike in the channel domain are coherent and therefore further help improve sparsity in the corresponding FK domain. The higher sparsity provided by a 3D FK transform is key to the successful thresholding and deblending.

In one-sided WAZ acquisition, the NAZ and WAZ shots are fired alternately from two separate vessels. When the shot gathers are sorted by time, this alternation produces a 3D volume in which NAZ and WAZ data are interleaved, reducing sparsity in the FK domain and complicating the deblending process. Any additional irregularity, such as missing shots from either vessel, further degrades the coherence of the volume and exacerbates the challenge.

To address the interleaving of NAZ and WAZ shots, we separate the shot gathers into two independent sub-volumes, each containing data from only one vessel. This produces one NAZ sub-volume and one WAZ sub-volume. Although this separation increases the effective shot spacing and could introduce FK-domain aliasing, the Angola 3D example demonstrates that in terms of thresholding aliasing appears “signal” and help yield a high-quality deblended result in the sub-volume approach. This differs from the negative impact of aliasing in data interpolation or regularization and other up sampling applications.

In the proposed workflow, the thresholding level is defined by the maximum FK amplitude observed across both sub-volumes, while the thresholding itself is applied independently to each one. Reblending is then conducted in the time domain following the conventional procedure.

Examples

The Angola 3D data was acquired in southern Atlantic with two vessels. As in Figure 1, one vessel towed twelve 10 km long streamers 150 m apart; the other one was dedicated to shooting abeam the spread streamers 1800 m from the center, where the red dots represent the sources. Triple enhanced-frequency sources (Brittan *et al.* 2020) were deployed on each vessel. The sources on the streamer vessel are 1, 2 and 3, and 4, 5 and 6 on the dedicated source vessel. The shot interval is 16.67 m and 100 m per same source, with shot pattern 1-4-2-5-3-6.

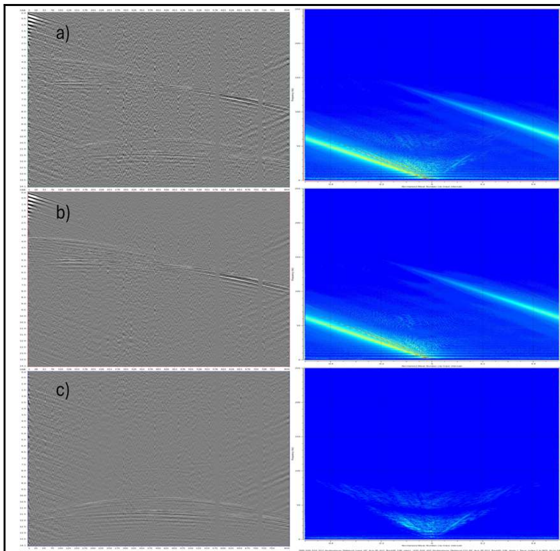

Figure 3: Shot gather FK spectrum analysis of NAZ data deblending. (a) input, (b) deblended model, and (c) difference. FK spectrum is shown on the right.

In Figure 2, we present simultaneous-source one-sided WAZ data deblending in shot domain for two consecutive shots, the left one is NAZ shot gather and the right one is WAZ shot gather in each small plot. Figure 2(a) is the input; 2(b) is the deblended model, and 2(c) is the difference. On the right-hand side lies the closeup of the cyan box. The blending noise in the NAZ data is just the signal in the WAZ data and vice versa. Deblending resolves the interference and recovers each gather with just its own energy.

In Figure 3, we present the FK analysis of shot domain NAZ data from one source and one cable before and after deblending. The aliasing events in the NAZ data do not affect the deblending at all, and the signals are precisely captured. This is because strong aliasing is treated as if it were signals in the process of thresholding. No attempts to remove aliasing are undertaken unlike in data interpolation or reconstruction as blending noise is the only thing desired to remove in this case.

In Figure 4, deblending result is presented in channel domain. Figure 4(a) is the input; 4(b) and 4(c) are the deblended model and the difference. The signals are truly preserved at the water bottom and in deep section, while the blending noise is cleaned. The deblending is robust even in the area with strong swell noise on the left of the figure.

In Figure 5, we show the shot-domain octave analysis of NAZ data from one source and one cable before and after deblending. Figure 5(a) is the input; 5(b) and 5(c) are the deblended model and difference. The low-frequency events and blending noise can be differentiated down to 0-2 Hz, which honours the rich low-frequency content of enhanced-frequency sources and will benefit FWI model building. The blending noise is cleaned in every spectrum band while signals are well preserved.

In Figure 6, we show the stacking results of both NAZ and WAZ data from one gun and one cable. Figure 6(a) – 6(c) are the NAZ input, deblended model and difference; and at the bottom 6(d) – 6(f) are the WAZ counterparts. The results demonstrate that the water bottom and other geological events are preserved with high fidelity with no leakage, and the blending noise from both previous and next shots are removed clean. The sharp boundary of water bottom and subtle events at the deep are revealed after deblending.

Detailed and comprehensive quality check in various domains help ensure high fidelity deblended data. This is crucial as deblending is the first step of processing and set the base for high quality migration.

Conclusions

Simultaneous-source one-sided WAZ acquisition with low-frequency sources has been introduced in frontier areas with complex geological structures as it can provide better illumination at depth in an efficient and economic manner. However, this type of acquisition can also raise challenges in processing to honour the extraordinarily complex data, particularly in deblending.

Three-dimensional volume comprising interleaved NAZ and WAZ shot gathers are not ideal for existing deblending methods. Thus, a new strategy was applied to overcome the challenges. The data are sorted into two sub-volumes by source vessel, and one unique thresholding function is defined. Thresholding is performed on the two sub-volumes separately.

The example from a complex salt setting offshore Angola demonstrates that the proposed method delivers high-quality deblending performance. Signal content is preserved in both the WAZ and NAZ sub-volumes down to the 0–2 Hz band with no observable leakage, and the complex data retain excellent amplitude fidelity throughout the process.

Moreover, the approach generalizes naturally to multi-vessel acquisition scenarios, regardless of the number or configuration of vessels. The only requirement is to partition the initial 3D shot-gather volume into separate sub-volumes according to vessel origin.

It may also be used for OBN and land deblending. Only data needs to be processed in cross-spread domain as in the streamer case unlike traditional land or OBN deblending in the receiver domain. More work should be done in this area.

Acknowledgements

We thank TGS for the permission to show the data examples above.

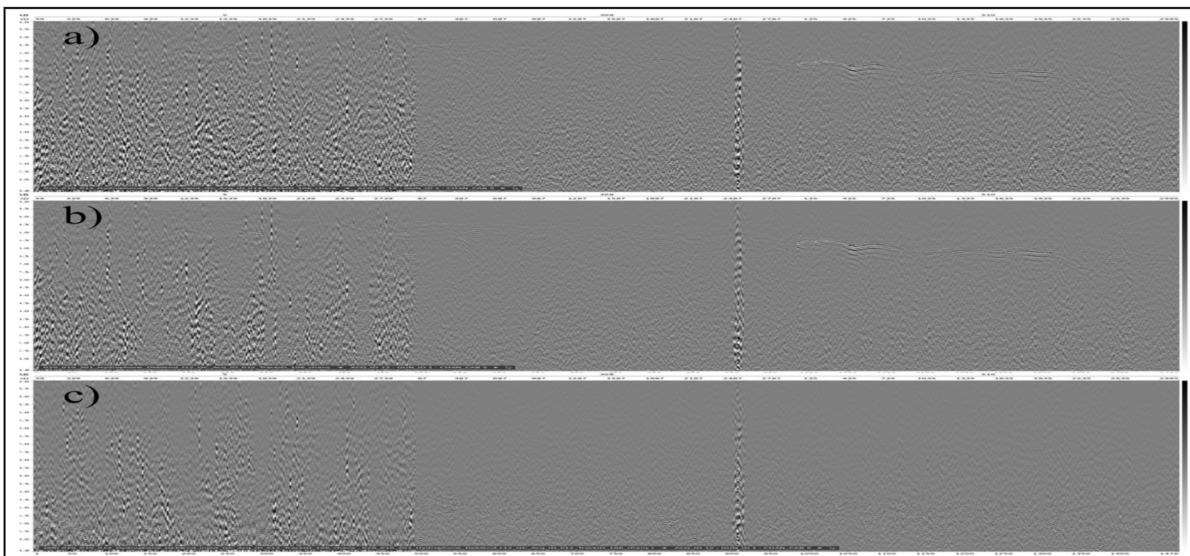

Figure 4: Channel gather deblending. (a) input, (b) deblended model, and (c) difference.

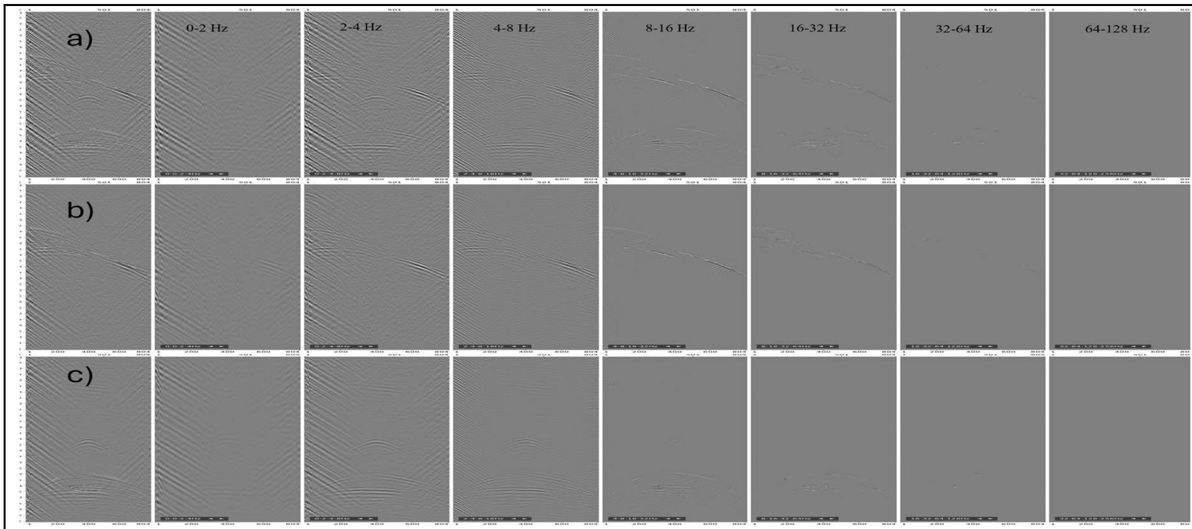

Figure 5: Shot gather octave analysis. (a) input, (b) deblended model (c) difference.

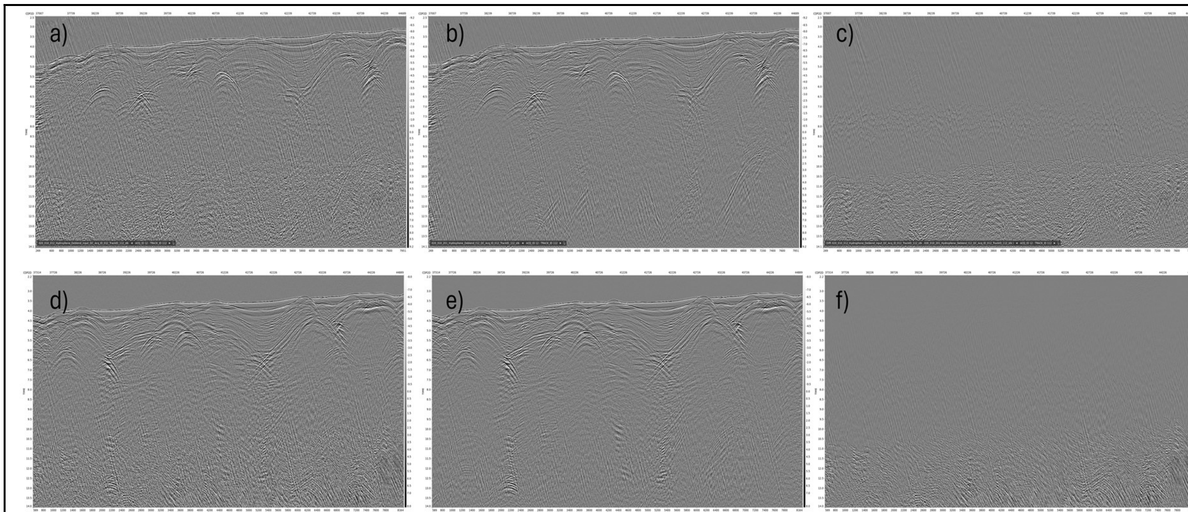

Figure 6: Stacking of NAZ data and WAZ data. (a)-(c) are the NAZ input, deblended model and difference; (d)-(f) are the WAZ counterparts.